SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELAXATION REQUEST FROM ORDER EA-03-009 REGARDING THE

CONTROL ELEMENT DRIVE MECHANISM EXAMINATION

FACILITY OPERATING LICENSE NO. NPF-6

ENTERGY OPERATIONS, INC.

ARKANSAS NUCLEAR ONE, UNIT 2

DOCKET NO. 50-368

1.0 INTRODUCTION

Order EA-03-009, issued on February 11, 2003, requires specific examinations of the reactor pressure vessel (RPV) head and vessel head penetration (VHP) nozzles of all pressurized water reactor plants. Section IV, Paragraph F, of the Order states that the Director, Office of Nuclear Reactor Regulation, may, in writing, relax or rescind any of the conditions set forth in Section IV, Paragraph C of the Order upon demonstration by the licensee of good cause. Section IV, Paragraph F, of the Order states that a request for relaxation regarding inspection of specific nozzles shall address the following criteria: (1) the proposed alternative(s) for inspection of specific nozzles will provide an acceptable level of quality and safety, or (2) compliance with this Order for specific nozzles would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety. In addition, Section IV, Paragraph F, of the Order states that requests for relaxation of the Order associated with specific penetration nozzles will be evaluated by the Nuclear Regulatory Commission (NRC) staff using the procedure for evaluating proposed alternatives to the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code) in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) 50.55a(a)(3).

For Arkansas Nuclear One, Unit 2 (ANO-2) and similar plants determined to have a high susceptibility to primary water stress corrosion cracking (PWSCC), in accordance with Section IV, Paragraphs A and B of the Order, the following inspections are required to be performed every refueling outage in accordance with Section IV, Paragraph C.(1) of the Order:

(a) Bare metal visual examination of 100% of the RPV head surface (including 360° around each RPV head penetration nozzle), AND

(b) Either:

(i) Ultrasonic testing of each RPV head penetration nozzle (i.e., nozzle base material) from two (2) inches above the J-groove weld to the bottom of the nozzle and an assessment to determine if leakage has occurred into the interference fit zone, OR

(ii) Eddy current testing or dye penetrant testing of the wetted surface of each J-Groove weld and RPV head penetration nozzle base material to at least two (2) inches above the J-groove weld.

Footnote 3 of the Order provides specific criteria for examination of repaired VHP nozzles.

By letter dated August 27, 2003, as supplemented by letters dated September 12, September 25, October 2, and October 8, 2003, Entergy Operations, Inc. (Entergy, the licensee) requested relaxation to implement an alternative to the requirements of Section IV, Paragraph C.(1)(b)(i), of the Order for all control element drive mechanism (CEDM) nozzles at ANO-2. The August 27, 2003, relaxation request supersedes a request made on June 11, 2003. The licensee also provided information at a public meeting held at NRC headquarters in Rockville, Maryland on August 14, 2003. (An electronic copy of the August 14, 2003, meeting summary may be found in the Agencywide Documents Access and Management System, accession number ML032410436.)

2.0 RELAXATION REQUEST FOR RPV HEAD CEDM PENETRATION NOZZLES, ORDER NO. EA-03-009

2.1 Order Requirements for Which Relaxation is Requested

Section IV.C.(1) of Order EA-03-009 requires, in part, that the following inspections be performed every refueling outage for high susceptibility plants similar to ANO-2:

(a) Bare metal visual examination of 100% of the RPV head surface (including 360° around each RPV head penetration nozzle), AND

(b) Either:

(i) Ultrasonic testing of each RPV head penetration nozzle (i.e., nozzle base material) from two (2) inches above the J-groove weld to the bottom of the nozzle and an assessment to determine if leakage has occurred into the interference fit zone, OR

(ii) Eddy current testing or dye penetrant testing of the wetted surface of each J-Groove weld and RPV head penetration nozzle base material to at least two (2) inches above the J-groove weld.

The licensee has requested relaxation from Section IV.C.(1)(b)(i) of the Order to perform ultrasonic testing (UT) of the RPV head penetration inside the tube from 2 inches above the J-groove weld to the bottom of the penetration. Specifically, the relaxation is related to UT examination of the bottom portion (threaded area) of all 81 CEDM penetration nozzles. The remaining nine RPV head penetrations are eight incore instrumentation penetrations and one RPV head vent line.

By supplement dated October 8, 2003, Entergy requested the relaxation for one operating cycle (operating cycle 17) commencing with the startup from the Fall 2003 refueling outage at ANO-2.

2.2 Licensee's Proposed Alternative Method

UT Examination

The licensee states that the inside diameter (ID) surface of each CEDM nozzle (i.e., nozzle base material) shall be ultrasonically examined from two (2) inches above the J-weld to 1.544 inches above the bottom of the nozzle. The licensee states that it will also perform an assessment to determine if leakage has occurred into the interference fit zone, as currently specified in Section IV.C.(1)(b)(i) of the Order. Figure 1 from the licensee's August 27, 2003, submittal shows the inspection areas of a CEDM nozzle as defined by the licensee.

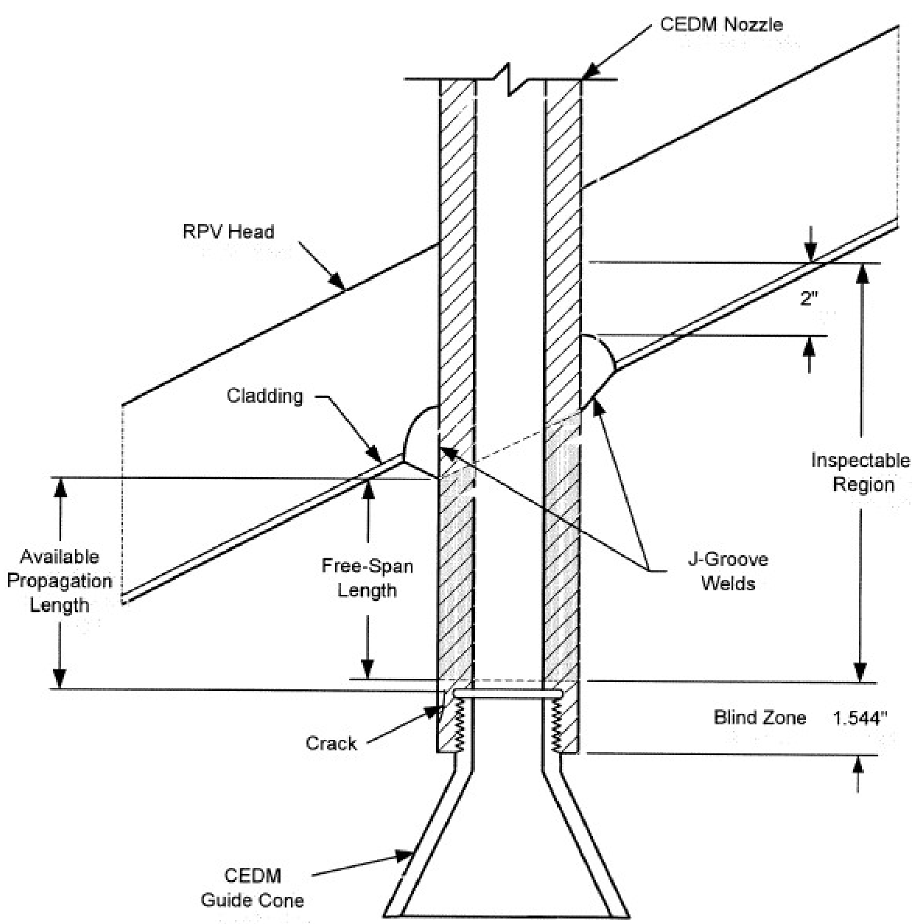

Figure 1

Augmented Examination:

The licensee states that nozzles without sufficient free-span length to facilitate one operating cycle of crack growth would be subject to an augmented inspection program. The licensee's proposed augmented inspection consists of either eddy current testing (ECT) or penetrant testing (PT), or a combination of both techniques within the free-span region. The augmented inspection of the outside diameter (OD) surface will be performed on the portion of the nozzle that has been determined by analysis as necessary to prevent a crack from reaching the J-groove weld in less than one operating cycle. The licensee's analysis indicates that a supplemental examination would be required on 75 of the 81 CEDM nozzles at ANO-2.

2.3 Licensee's Basis for Relaxation

Nozzle Configuration Limitation:

The licensee states that guide cones are attached to the bottom of the ANO-2 CEDM nozzles via threaded connections and screw into the end of the CEDM nozzles with a welded set screw and two tack welds at the cone-nozzle interface to secure the guide cone to the nozzle. In addition, there is a chamfer at the top of the threaded region that is 0.094 inch in length and the threaded region is 1.25 inches in length.

The licensee states that meaningful UT data cannot be collected in the threaded area or the chamfer region, since the chamfer region geometry causes sporadic signals. The licensee further states that, once the guide cone is reached, sound cannot pass into the CEDM nozzle base material because of the gap that exists between the guide cone and the nozzle at the threaded connection. This leaves a length of 1.344 inches (1.25 + 0.094) at the bottom of the CEDM nozzle that cannot be inspected by UT examination due to nozzle configuration.

The licensee states that resolving the UT limitations due to nozzle configuration would require eliminating the CEDM nozzle-to-guide cone threaded connection, which would require cutting off the top of the nozzle thread region and changing it to a welded socket design for attachment of the guide cone, and the aforementioned modification would result in a total personnel exposure of 101.25 man-rem and a reduction in the inspection region between the blind zone and the J-groove weld. The licensee further states that installing the new guide cones would result in high residual stresses in the weld heat affected zone, which would increase the probability of PWSCC.

Inspection Probe Limitation Design:

The licensee states that, in addition to the limitations of inspecting the chamfer and threaded area of the bottom of the CEDM nozzles, there are limitations regarding the inspection probe's ability to collect data 0.2 inches above the chamfer area. The licensee states that the inspection probe that is to be used for the ANO-2 CEDM nozzles consists of seven (7) individual transducers. The transducers consist of one pair used for circumferential scanning using time-of-flight diffraction (TOFD), one pair for axial scanning using TOFD, one standard zero-degree scan transducer, and two eddy current transducers. These transducers are slightly recessed into the probe holder that must be filled with water to provide coupling between the transducers and the nozzle wall. The licensee states that prior UT examinations performed on the CEDM nozzles at ANO-2 indicate that the circumferential scanning TOFD transducer pair only collects data down to a point 0.200 inch above the chamfer. This makes the total distance at the bottom of the nozzle that cannot be UT inspected equal to 1.544 inches (1.25 in threads + 0.094 inch chamfer + 0.2 inch). The licensee refers to this area as the "blind zone" and states that it knows of no UT equipment currently available that resolves the blind zone limitation, and, therefore, new UT equipment would have to be developed and appropriately qualified. The licensee also states that the time and resources required to develop this equipment are unknown.

Entergy states that it evaluated the feasibility of inspecting the blind zone (ID and OD surfaces) using the PT or ECT method as specified in Section IV.C.(1)(b)(ii) of the Order. In order to perform a PT examination, it would be required to remove all 81 of the CEDM cones, perform a PT examination, and reinstall all 81 CEDM cones, which would result in a total personnel exposure of approximately 202.5 man-rem. The licensee further states that performing a ECT examination, as with a UT inspection, would not yield results in the 1.344 inch threaded region.

In summary, Entergy states that removing the CEDM nozzle guide cones and reinstalling new nozzle guide cones in order to remove the threaded area, or removing and reinstalling the existing nozzle guide cones to conduct additional inspections, would impose hardships and unusual difficulties without a compensating increase in the level of quality and safety.

<u>Crack Growth Analysis</u>:

As a result of the aforementioned non-destructive examination limitations, the licensee states that it performed an analysis to determine if sufficient free-span length exists between the blind zone and the weld that would allow one operating cycle of crack growth without the postulated crack reaching the reinforcing fillet of the J-groove weld. For nozzles or portions of nozzles that did not have sufficient free span length to accommodate one operating cycle of crack growth, the licensee states that it determined how much propagation length is required before a postulated crack in the blind zone would reach the weld within one operating cycle. The analysis showed that seventy-five (75) of eighty-one (81) CEDM nozzles did not have sufficient free-span length to accommodate one operating cycle of crack growth. As a result, the licensee proposed performing an augmented inspection of the OD of a sample population that represented approximately 20% of the 75 CEDM nozzles that require augmented inspection. After discussions with the staff, the licensee submitted a letter dated September 12, 2003, that withdrew the sampling plan and proposed performing an augmented inspection on all 75 CEDM nozzles that did not have enough free-span length to accommodate one operating cycle of crack growth.

The licensee states that ECT will be the primary inspection method for the augmented inspections, but the PT method or a combination of PT and ECT may also be used. The licensee provided a table listing the minimum inspection areas, axial length, and circumferential extent required to allow one operating cycle of growth for all 75 nozzles requiring augmented inspection. The maximum axial length that is required to be inspected, according to the licensee's analyses, is 0.661 inch, and the minimum axial length to be inspected is 0.320 inch below the blind zone for the 75 CEDM nozzles that require augmented inspection. The licensee states that it understands that the NRC staff's expectation is that inspections be performed to the maximum extent possible. According to the licensee, the ECT inspection tool is limited to inspecting an axial length from 0.20 inch above the blind zone to 0.80 inch below the top of the blind zone.

The licensee states that, while the table in its submittal indicates an axial length to be inspected ranging from 0.320 inch to 0.661 inch below the top of the blind zone, it will be inspecting to an axial distance of 0.8 inch below the top of the blind zone. The licensee states that the ECT inspection equipment was specifically designed by Westinghouse Electric Company to perform the required augmented inspections of the CEDM nozzles with the following objectives:

- Inspection coverage bounds the portion of the blind zone identified by analysis.
- The equipment can be consistently applied to all CEDM nozzle locations.
- The equipment setup and operation minimizes radiation exposure.
- The equipment setup and operation minimizes operator error.

According to the licensee, the ECT inspection tool is designed with an array of transducer coils that allow a single scan to be performed without multiple setups. A one-inch scan length (0.2 inch above the blind zone + 0.8 inch below the blind zone) was chosen to envelop the areas identified by analysis (maximum axial length of 0.661 inch), and to prevent interference issues associated with the guide cones and steep angles on the outer nozzle rows. The licensee explained that the scan length is fixed by the design of the inspection tool and the size of the ECT coil block.

The licensee's analysis is detailed in Entergy Engineering Report M-EP-2003-002, Revision 1, "Fracture Mechanics Analysis For The Assessments Of The Potential For Primary Water Stress Corrosion Crack (PWSCC) Growth in the Un-inspected Regions Of The Control Element Mechanism (CEDM) Nozzles At Arkansas Nuclear One Unit 2," which is Enclosure 2 to the supplemental letter dated August 27, 2003.

3.0 EVALUATION

The NRC staff's review of this request was based on Criterion (2) of Paragraph F of Section IV of the Order, which states:

> Compliance with this Order for specific nozzles would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Within the context of the licensee's proposed alternative examination of the RPV penetration nozzles, the licensee has demonstrated the hardship that would result from implementing examinations to the bottom end of the CEDM nozzles. The hardship identified by the licensee includes the nozzle configuration, limitation of the UT probe used for nozzle examination, and radiation exposure to perform UT examination in accordance with the Order. This evaluation focuses on the issue of whether there is a compensating increase in the level of quality and safety, such that these nozzles should be inspected despite this hardship.

To assess the likelihood of a postulated flaw in the uninspected portion of the nozzle propagating to the pressure boundary, the licensee performed a fracture mechanics analysis. Although Section XI of the ASME Code does not provide guidelines for characterizing postulated flaws for applications similar to the ANO-2 CEDM nozzle blind zones, it is reasonable to assume existence of the largest flaw that could exist in the blind zone consistent with engineering principles.

Once the postulated initial flaw size is determined, the applied stress intensity factor (applied K) for the crack is calculated to evaluate the crack growth according to an appropriate crack growth rate (CGR) for the Alloy 600 material. The objective is to determine whether the initial flaw will grow to the J-groove weld in one operating cycle. The stresses required for the applied K calculation are from a stress analysis using finite element method (FEM) modeling of the CEDM nozzle assembly. Evaluation of the technical elements mentioned above are discussed below.

The staff has evaluated the information regarding the FEM modeling. The licensee's FEM model considers welding processes by simulating melting and solidification of individual welding passes through a combination of thermal and structural models. Heat treatment history has also been considered. This method of calculating residual stresses is consistent with the industry practice and is acceptable to the staff. In addition, the licensee considers all test and operating loads. The basic stress-strain properties for Alloy 600 nozzle material and the Alloy 182 J-groove weld filler materials used in the stress analysis are generic in shape, which are modified based on certain basic material properties from ANO-2's certified material test report (CMTR). Considering the lack of plant-specific data, this engineering approach in modifying the generic stress-strain curve is appropriate. Further, the CMTR material property affects the maximum stress of the nozzle more than the generic stress-strain shape does to the stress, providing additional support to the licensee's approach. The use of the stress-strain law for an elastic-perfectly plastic model for the Alloy 182 filler metal may not be a good representation of the material's real behavior. However, it was used to overcome a modeling limitation of the FEM code so that more realistic stresses could result. In summary, the use of resulting stresses from the FEM model as input to the licensee's fracture mechanics evaluation is acceptable.

To assess the consequence of having flaws in the blind zone, the licensee assumed three initial flaw geometries in its fracture mechanics evaluation: an ID elliptical surface flaw 0.04627 inch deep and 0.32 inch long, an OD elliptical surface flaw 0.07932 inch deep and 0.32 inch long, and a through-wall flaw of length from the top of the blind zone to a point of hoop stress less than 10 ksi. Because the crack face of the assumed through-wall flaw is several times larger than that for an assumed ID or OD flaw, the through-wall flaw geometry is a conservative assumption. The licensee's analysis results in Table 19 of Enclosure 2 of the submittal dated August 27, 2003, indicates that this is not always true; for Case 14, where the available propagation length for the OD flaw is zero, the OD flaw assumption leads to more limiting results. The staff found that this exception is due to the licensee's approach of assuming the upper crack front for an initial OD or ID flaw to be 0.16 inch ahead of a corresponding through-wall flaw, making the OD flaw with no or very little available propagation length more limiting. The licensee's approach of assuming the upper crack front for an initial ID or OD flaw to be 0.16 inch beyond the upper blind zone limit is conservative, and the assumed initial flaw sizes for the analyzed cases are acceptable.

For applied K calculations for ID and OD flaws, the licensee used an influence-function approach based on extensive FEM analyses for thick cylinders with ID and OD surface flaws by S. R. Mettu, et al., (1992). For applied K calculations for through-wall flaws, the licensee used another influence-function approach based on extensive FEM analyses for thick cylinders with through-wall flaws by Christine C. France, et al., (1997). Using formulas for thick cylinders is appropriate because, for this application, the R/t ratio for the CEDM nozzle is 1.7.

For ID and OD flaws, the licensee calculated the applied K at the crack depth using the stress analysis results, fully considering the variation of stress distribution along the depth direction. Instead of using the conventional approach of estimating its value based on the aspect ratio of the crack and the applied K at the crack depth, the licensee evaluated the applied K at the upper crack front, directly using an average stress from the stress analyses results. The comparison made in the submittal indicates that the licensee's approach is more conservative than the conventional approach. However, being more conservative does not mean that the licensee's method using the "moving average scheme" is rigorous. The licensee's method does not consider the full contribution of the high stresses at the moving crack front region to the applied K. The staff determined that this deficiency need not be addressed because there is sufficient conservatism associated with the assumption of an initial OD flaw to be 0.16 inch outside the blind zone. In conclusion, the licensee's approach is acceptable for this application because it conservatively assumes an initial OD flaw having its upper crack front exceed the blind zone by 0.16 inch outweighs the slight deficiency associated with stress averaging.

The licensee used the results from the FEM stress analyses, the initial flaw sizes, and the fracture mechanics methodology discussed above to predict the crack growth of the upper crack front of a postulated flaw at the end of a fuel cycle. The results of the available propagation length versus the crack growth at the end of one fuel cycle are listed for four groups of representative CEDM nozzles at downhill, uphill, and mid-plane locations for each. For the critical downhill location for each group, additional fracture mechanics analyses were performed to determine the axial extent under the top of the blind zone and its circumferential extent where flaws cannot exist if one fuel cycle of operation is required. The complete results for the additional analyses and the boundaries for the proposed augmented inspection are in the supplement dated August 27, 2003.

Since the boundaries for the proposed augmented inspection, as defined in Table 21, are based on an acceptable fracture mechanics methodology, and the approach of inspecting the area below the top of the blind zone to ensure adequate propagation length for all assumed flaws to grow in one fuel cycle is reasonable, the staff accepts the results summarized in Table 21.

The aforementioned crack growth analysis used the approach described in Footnote 1 of the Order, with the exception of the CGR, as the criteria to set the necessary height of the surface examination. Therefore, the coverage addressed by this request provides reasonable assurance of structural integrity of the component. However, this analysis incorporates a crack growth formula different from that described in Footnote 1 of the Order, as provided in the Electrical Power Research Institute Report, "Material Reliability Program (MRP) Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick Wall Alloy 600 Material (MRP-55), Revision 1." The NRC staff has completed a preliminary review of the crack growth formula but has not yet made a final assessment regarding the acceptability of the report. If the NRC staff finds that the crack growth formula in industry report MRP-55 is unacceptable, the licensee shall revise its analysis that justifies relaxation of the Order within 30 days after the NRC informs the licensee of an NRC-approved crack growth formula. If the licensee's revised analysis shows that the crack growth acceptance criteria are exceeded prior to the end of the current operating cycle, this relaxation is rescinded and the licensee shall, within 72 hours, submit to the NRC written justification for continued operation. If the revised analysis shows that the crack growth acceptance criteria are exceeded during the subsequent operating cycle, the licensee shall, within 30 days, submit the revised analysis for NRC review.

If the revised analysis shows that the crack growth acceptance criteria are not exceeded during either the current operating cycle or the subsequent operating cycle, the licensee shall, within 30 days, submit a letter to the NRC confirming that its analysis has been revised. Any future crack growth analyses performed for this and future cycles for RPV head penetrations must be based on an acceptable CGR formula. By letter dated October 2, 2003, the licensee modified its alternative to include condition.

Augmented Inspection:

According to the licensee, of the 81 CEDM nozzles at ANO-2, 75 of the nozzles will not receive UT coverage of enough nozzle material below the J-groove weld to sustain crack growth of a postulated flaw over one operating cycle. The aforementioned nozzles will receive an augmented inspection to a minimum distance, as shown in Table 1 in the licensee's September 12, 2003, supplemental letter. The licensee's analysis shows that these minimum distances will accommodate one operating cycle of crack growth. Although the analysis shows an axial length to be inspected ranging from 0.320 inch to 0.661 inch below the top of the blind zone, the licensee states that it will be inspecting an axial length of 0.8 inches below the top of the blind zone. The licensee stated that augmented examinations will be performed using ECT, PT, or a combination of both inspection methods. It must be noted that UT examination is a volumetric examination of the base metal and gives a higher level of interrogation than an ECT or PT examination, which inspects the surface only. However, the licensee's analysis shows that an ID-initiated flaw in the blind zone in any of the CEDM nozzles will not propagate to the J-groove weld in one operating cycle. According to the licensee's analysis, through-wall and OD part through-wall flaws are the limiting flaws as established by analysis. The ECT and PT examination methods are very effective in locating surface flaws. It is highly likely that ECT or PT will locate surface flaws in the inspection area if they are present. Performing a surface examination to 0.8 inches below the top of the blind zone is acceptable.

Based on the results from the crack growth analysis and the proposed augmented inspections, there is reasonable assurance of structural integrity for the uninspected portions of the nozzles. Therefore, performance of UT to the bottom of the CEDM nozzles would result in hardship without a compensating increase in the level of quality and safety.

The staff finds that the licensee's proposed alternative examination of the CEDM RPV head penetration nozzles using UT from 2 inches above the J-groove weld to 1.544 inches above the bottom of the CEDM nozzles, and the augmented examination of nozzles without sufficient free-span length, provide reasonable assurance of the structural integrity of the RPV head, VHP nozzles, and welds. Further inspection of the CEDM nozzles in accordance with Section IV.C.(1)(b)(i) of Order EA-03-009 would result in hardship without a compensating increase in the level of quality and safety. Therefore, pursuant to Section IV, Paragraph F, of Order EA-03-009, good cause has been shown for relaxation of the Order, and the staff authorizes, for one operating cycle commencing with the startup from the Fall 2003 refueling outage, the proposed alternative inspection for all CEDM head penetration nozzles at ANO-2, subject to the following condition:

> If the NRC staff finds that the crack-growth formula in MRP-55 is unacceptable, Entergy shall revise its analysis that justifies relaxation of the Order within 30 days after the NRC informs Entergy of an NRC-approved crack-growth formula. If Entergy's revised analysis shows that the crack growth acceptance criteria are exceeded prior to the end

of the operating cycle which follows the current refueling outage, this relaxation is rescinded and Entergy will, within 72 hours, submit to the NRC written justification for continued operation. If the revised analysis shows that the crack growth acceptance criteria are exceeded during the subsequent operating cycle, Entergy shall, within 30 days, submit the revised analysis for NRC review. If the revised analysis shows that the crack growth acceptance criteria are not exceeded during either the upcoming operating cycle or the subsequent operating cycle, Entergy shall, within 30 days, submit a letter to the NRC confirming that its analysis has been revised. Any future crack-growth analyses performed for the upcoming operating cycle and future cycles for RPV head penetrations will be based on an NRC-acceptable crack growth rate formula.

4.0 CONCLUSION

The staff concludes that the licensee's proposed alternative examination of the CEDM RPV head penetration nozzles using UT from 2 inches above the J-groove weld to 1.544 inches above the bottom of the CEDM nozzles, and the augmented examination of nozzles without sufficient free-span length, provide reasonable assurance of the structural integrity of the RPV head, VHP nozzles, and welds. Further inspection of the CEDM nozzles in accordance with Section IV.C.(1)(b)(i) of Order EA-03-009 would result in hardship without a compensating increase in the level of quality and safety. Therefore, pursuant to Section IV, Paragraph F, of Order EA-03-009, good cause has been shown for relaxation of the Order, and the staff authorizes, for one operating cycle commencing with the startup from the Fall 2003 refueling outage, the proposed alternative inspection for all CEDM head penetration nozzles at ANO-2, subject to the following condition:

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Date: October 9, 2003